THE EFFECT OF SURROUNDING MEDIUM ON THE DIELECTRIC STRENGTH OF LAC AND LAC-MOULDED MATERIALS

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Plate VIII

ABSTRACT. The dielectric strength of lac and different lac moulding compositions have been determined using a brass sphere and a plate electrode. Six different liquid media, *viz.*, transformer oil, xylol, kerosene, turpentine, castor oil and a mixture of xylol and acetone have been used successively in the test jar. It has been found from the results of the experiment that the specific resistance and not the dielectric constant of the liquid media is effective in making a difference in the breakdown voltage values. The effect of thickness of specimens on the dielectric strength has also been studied in each of the above liquid media and it has been observed that the general logarithmic law between the thickness and the breakdown voltage values also holds good for lac as well as other moulded lac specimens. The constants for such a law have been evaluated for these materials in different surrounding media. The nature of breakdown has been discussed and has been shown in a few photomicrographs.

INTRODUCTION

Data on the dielectric strength of insulating materials are of utmost practical utility, although it is still a disputable point whether the dielectric strength of a material is a physical constant of the material or is only an effect resulting from the method of measurement. Whatever it may be, the value of the dielectric strength of a material under actual operating conditions is of extreme importance in designing electrical machineries. There are so many uncertain factors associated with the mechanism of failure of electrical insulating materials, especially solid dielectrics, that the fundamental information regarding the breakdown of solid materials is still lacking. A large amount of data has, however, been collected by different workers on various materials owing principally to their practical utility. Whitehead[1] has presented these data in a systematic manner whilst Peek[2] and Schwaiger[3] have also dealt with this important subject in order to find out a satisfactory theory regarding the breakdown by analysis of previous data. The importance of the elimination of 'edge-effect' in determining the electric strength of materials was first shown by Moscicki[4], and a great advance has been made by Inge and his collaborators[5] since then, towards a better understanding of the problem.

The effect of surrounding medium on the breakdown of solid dielectrics has also been the subject of much speculation Littleton and Shaver[6] reported their results of test on insulators under oils containing different amounts of moisture. Inge and Walther[7], however, used liquids of known properties and they found that the specific resistance of the medium is only effective in making a difference in dielectric strength measurements.

The present paper presents the results of test on shellac and shellac-urea-formaldehyde-wood-flour-filled moulded discs in different liquid media.

EXPERIMENTAL

The test-specimens were all moulded discs of 4″ diameter, but of different thickness. Pure Kusum shellac was used for making shellac specimens. The moulding technique has already been described by Karim[8] and the same procedure was adopted except that tin foils were not used since it was found that these were not necessary when the mould was polished with french chalk powder after each operation. These discs were all desiccated for more than a week in a vacuum desiccator before they were tested. Electrodes were a sphere and a flat plate made of brass, the lower electrode being the plate. Six liquids, *viz.*, transformer oil, xylol, kerosene, turpentine, castor oil and a mixture of xylol and acetone were used successively in the test jar and discs of different thickness were employed in order to find out the effect of thickness on the breakdown voltage in each liquid medium. The rate of application of voltage was approximately 0.5 KV. per second. The voltage was measured by means of a Starke-Schroeder electrostatic voltmeter on the secondary side of the H.T. transformer, the primary of which was fed from a 50-cycle sine-wave alternator. The control was in the field of the alternator. The thickness measurements were made near the point of breakdown by means of a micrometer screw-gauge.

RESULTS

The results are given in Tables I and II.

TABLE I

Material—Kusum shellac

Surrounding medium	Thickness of specimen in mm.	Breakdown voltage in KV.	Dielectric strength in KV./mm.	Remark
Castor oil	1.22	25.2	20.6	
	1.48	29.0	19.6	
	1.62	30.0	18.4	
	2.05	34.8	17.0	
	2.45	38.2	15.6	Mean of 2 readings
	2.53	37.8	14.9	
	3.06	41.0	13.4	Mean of 2 readings

TABLE I (*contd.*)

Surrounding medium	Thickness of specimen in mm.	Breakdown voltage in KV.	Dielectric strength in KV./mm	Remark
Transformer oil	1.03	26.4	25.7	Mean of 2 readings
	1.63	32.8	20.1	
	1.88	35.2	18.7	
	1.98	36.0	18.2	
	2.50	40.8	16.3	Mean of 3 readings
	2.91	45.2	15.5	
	3.01	44.0	14.6	
Kerosene oil	0.91	26.0	28.6	
	1.06	28.0	26.4	
	1.43	30.9	22.9	
	1.62	34.8	21.1	
	1.85	37.0	20.0	
	2.02	39.6	19.7	Mean of 3 readings
	2.52	42.4	16.8	Mean of 2 readings
	3.02	46.8	15.4	
Xylol	1.18	31.0	26.0	
	1.25	31.8	25.4	
	1.45	34.0	23.4	
	2.00	40.5	20.2	
	2.49	45.1	18.3	
	2.95	52.5	17.6	
	3.02	49.4	16.3	
Turpentine	1.18	28.6	24.2	
	1.40	34.0	24.3	
	1.45	33.2	22.9	
	1.63	41.0	25.1	
	1.99	40.0	20.1	
	2.08	41.0	19.7	Mean of 2 readings
	2.10	39.8	19.3	
	2.40	48.0	20.0	
	2.85	53.0	18.6	
Xylol + 12% Acetone	0.98	51.0	52.0	
	1.05	59.0	56.2	
	1.07	58.0	54.2	
	1.46	64.0	43.8	
	1.50	62.8	41.8	
	1.52	72.0	47.3	
	1.95	82.0	42.0	
	2.03	84.0	41.4	
	2.38	95.0	40.0	
	2.45	98.0	40.0	
	2.54	96.0	38.8	

DISCUSSIONS

Choice of electrodes.—Experiments carried out for the British Electrical and Allied Industries Research Association have yielded results on the basis of minute test such that for good dielectrics, such as ebonite, etc., a sphere and plate electrode generally gave higher values than two discs. Particularly for thick specimens the disc electrodes gave lower values of B.D.V. than the sphere and plate owing probably to more flux-concentration at the edges of the

TABLE II

Material—Shellac-urea-formaldehyde-wood-flour composition

Surrounding medium	Thickness of specimen in mm	Breakdown voltage in KV.	Dielectric strength in KV./mm.	Remark
Castor oil	0.54	16.0	29.7	
	0.76	18.8	24.9	
	0.80	19.6	24.5	
	0.87	21.0	24.1	Mean of 2 readings
	1.60	28.0	17.5	
	1.67	28.0	16.8	
	1.71	26.2	15.3	
	1.76	26.0	14.8	
	1.88	30.0	16.0	
	2.10	30.0	14.3	
	2.13	30.6	14.5	
	2.88	34.8	12.1	
	3.02	34.8	11.5	
Transformer oil	0.59	20.0	33.9	
	0.70	20.8	29.7	
	0.73	19.8	27.2	
	0.96	23.4	24.4	Mean of 2 readings
	1.32	27.0	20.4	
	1.40	28.2	20.2	
	1.62	30.4	18.9	
	1.74	28.8	16.6	
	1.92	35.0	18.2	
	2.04	34.0	16.8	
	2.48	36.8	14.8	
	2.75	40.2	14.6	
	2.90	39.6	13.7	
	2.97	38.6	13.1	
	3.02	38.0	12.6	
Kerosene oil	0.61	19.0	31.2	
	0.64	20.0	31.2	
	0.82	22.0	26.9	
	1.14	25.8	22.6	
	1.39	29.8	21.1	
	1.72	32.8	19.1	
	1.95	34.0	17.4	
	2.13	36.0	16.9	
	2.37	40.2	17.0	
	2.45	39.4	16.1	
	2.47	41.0	16.6	
	2.55	42.4	16.7	
	2.96	45.4	15.4	
	3.03	47.2	15.6	
	3.08	46.8	15.2	
	3.12	49.0	15.7	
Xylol	0.55	21.2	38.6	
	0.73	24.2	33.2	
	0.83	26.8	32.3	
	0.88	29.0	32.9	
	0.96	28.0	29.2	
	1.21	30.8	25.5	
	1.30	33.0	25.4	
	1.61	38.2	23.7	
	1.86	41.4	22.2	
	2.01	44.0	21.9	
	2.12	45.0	21.3	
	2.46	48.8	19.9	
	2.96	58.0	19.6	
	3.14	56.4	18.0	

TABLE II (*contd.*)

Surrounding medium	Thickness of specimen in mm.	Breakdown voltage in KV	Dielectric strength in KV./mm	Remark
Turpentine	0.76	30.0	39.5	
	0.88	35.0	39.8	
	0.93	35.0	37.7	
	1.00	36.0	36.0	
	1.42	43.6	30.7	
	1.63	43.0	26.4	
	1.80	45.6	25.3	Mean of 3 readings
	2.11	52.8	25.1	
	2.14	49.8	23.3	
	2.22	51.8	23.4	
	2.90	60.0	20.7	
	3.02	64.0	21.0	
	3.11	62.0	20.0	
Xylol + 12% Acetone	0.62	27.0	43.6	
	0.72	26.0	36.1	
	0.85	30.0	35.3	
	0.92	37.8	41.0	
	0.98	34.0	34.7	
	1.32	47.0	35.6	Mean of 2 readings
	1.50	50.0	33.3	
	1.52	48.4	31.8	
	1.83	62.0	33.8	
	2.12	62.0	29.2	
	2.30	67.0	29.1	
	2.45	69.2	28.2	
	2.56	71.0	27.7	
	2.58	72.6	28.2	

former. We know that the electrostatic field between a sphere and a plate is similar to that between two equal spheres, and is practically uniform if the distance between them is small compared to the radius of the sphere. When it is intended to see the effect of the surrounding medium on the breakdown voltage, the sphere should simply be pressed on the specimen instead of having been imbedded in the material. For, in that case the results will, to a certain extent, depend upon the medium, as a layer of this medium will always surround the electrodes except at the centre. In these experiments, therefore, the choice was made of a sphere and plate electrode.

The Variation of Dielectric Strength with Thickness.—The variation of the breakdown voltage with the thickness of lac as well as of shellac-urea-formaldehyde-wood-floor composition has been shown graphically in Figs. 1 and 4. For most of the insulating materials the dielectric strength decreases with increasing thickness according to some function of the thickness. The most generally accepted formula for this function is given by

$$V = At^{n},$$

where V = the breakdown voltage,

t = the thickness of the specimen,

A and n are constants, the value of n being less than unity.

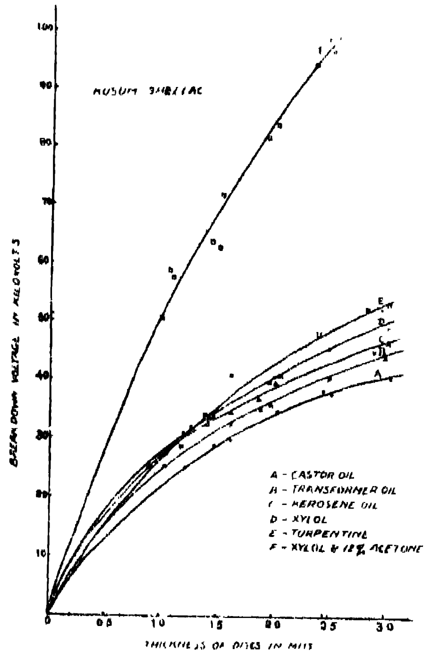


FIG. 1

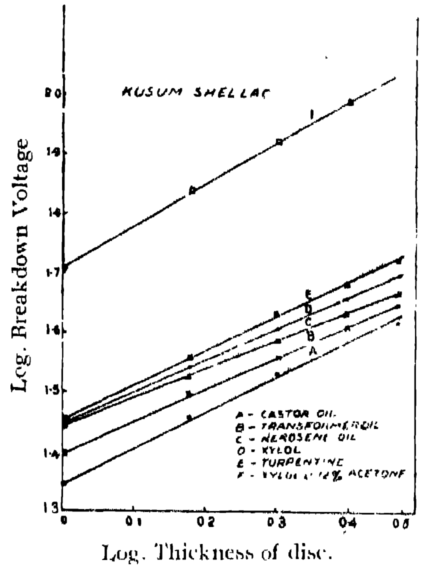


FIG. 2

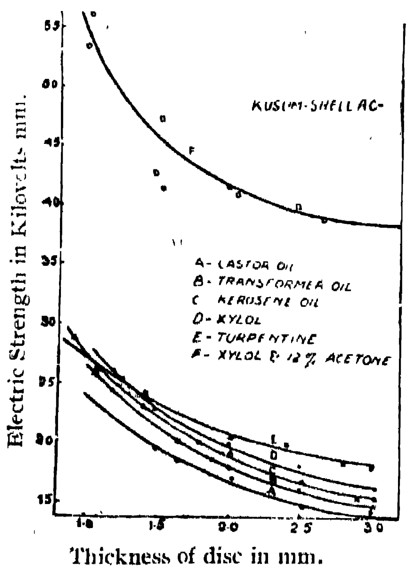


FIG 3.

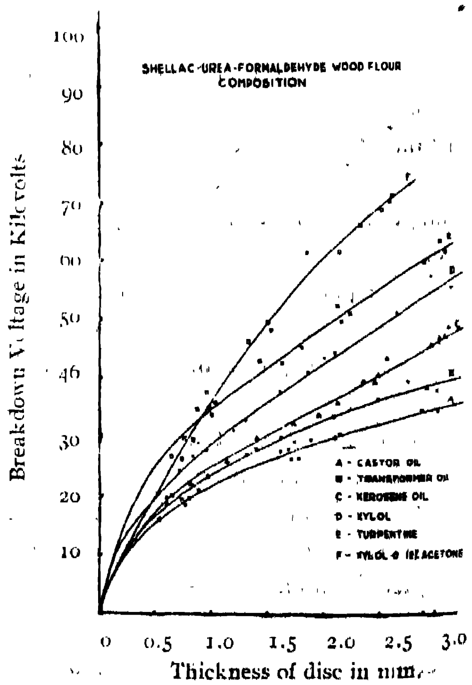


FIG. 4

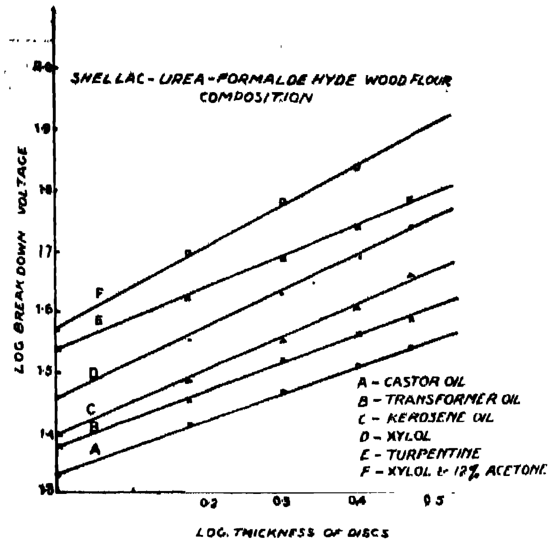


FIG. 5

For lac as well as shellac moulded materials this formula has been found to be applicable. The straight lines obtained by the plot of logarithm of breakdown voltage against logarithm of thickness have been shown in Figs. 2 and 5. The values of the constants A and n have been evaluated from these straight lines by the method of selected points.[9] The variation of dielectric strength with thickness in the case of lac has been shown in Fig. 3. The curves are hyperbolic in nature and these may obviously be explained from the general equation obtaining between the breakdown voltage and thickness of lac materials, *viz.*, $V = At^n$, where n is less than unity.

Since we have, $$V = At^n$$

$$\frac{V}{t} = At^{n-1}$$

or, $$v = At^{n-1} = At^{-(1-n)} = At^{-n'}$$

where v = dielectric strength and n' is a positive quantity.

The last equation is of the general form of a hyperbolic curve. The value of n' can also be obtained from n, since $n' = 1 - n$, the same value of A being applicable for both the equations. The values of these constants A, n and n' for both Kusum shellac and shellac-urea-formaldehyde-wood-flour composition have been included in Table III. Here the breakdown voltage, V, or the dielectric strength, v, is expressed in kilo-volts and the thickness, t, in millimetres.

The effect of medium.—It may be seen from the curves in Figs. 1 and 4 that the castor oil gave the lowest dielectric strength values among the liquids used for shellac as well as shellac-urea-formaldehyde-wood-flour composition. The liquid

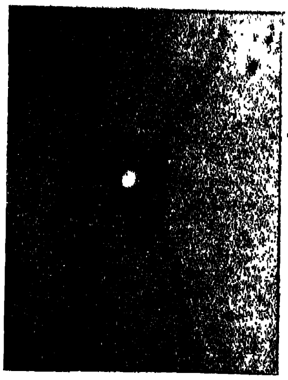
TABLE III

Surrounding medium	Kusum shellac			Shellac-urea-formaldehyde-wood-flour composition		
	A	n	n'	A	n	n'
Castor oil	22.10	0.608	0.392	21.50	0.450	0.550
Transformer oil	24.87	0.542	0.458	23.90	0.467	0.533
Kerosene oil	27.66	0.483	0.517	25.19	0.538	0.462
Xylol	27.92	0.542	0.458	28.45	0.608	0.392
Turpentine	28.41	0.585	0.415	34.67	0.525	0.475
Xylol + 12% acetone	50.90	0.708	0.292	37.87	0.667	0.333

TABLE IV

Surrounding liquid medium	Specific resistance	Dielectric constant
Castor oil	2×10^{13}	4.58
Transformer oil	7×10^{12}	2.20
Kerosene oil	5×10^{11}	2.10
Xylol	6×10^{10}	2.36
Spt. of turpentine	7×10^{8}	2.23
Xylol + 12% acetone	1×10^{8}	3.12

media when arranged in ascending order of dielectric strength of lac will be castor oil, transformer oil, kerosene oil, xylol, spt. of turpentine, and a mixture of xylol and 12% acetone. These liquids were chosen since they have varying specific resistance and different dielectric constant values. The data regarding their specific resistance and dielectric constant are shown in Table IV. The order of curves of dielectric strength in different liquid media naturally shows that it is the specific resistance and not the dielectric constant which is effective in making a difference in the breakdown voltage values. It may be quite possible, however, that the values of dielectric constant and specific resistance measured at low voltages are quite different from those obtained at very high voltages, especially near the point of discharge or breakdown. It is very difficult to determine the conditions of the surrounding medium under very high voltage stress nearing breakdown. In any case the relation between the gradually decreasing value of specific resistance of the liquid media measured at low voltages and the increasing dielectric strength values of the lac is striking. Similar results were also noticed by Inge and Walther[7] in the case of glass. They found that the specific resistance of the medium was responsible for eliminating preliminary failure of the surrounding



(A) ×8

(B) ×8

(C) ×8

(D) ×8

Photomicrographs of puncture

dielectric, thus making a wide difference in the results of test on the same insulator. The dielectric constants of shellac-urea-formaldehyde-wood-flour composition and castor oil may be considered to be approximately identical at low voltages, but the relation between the breakdown voltage and the thickness of the former in the medium of the latter was not even approximately linear. Naturally, it is not due to the non-homogeneity of the electric field that the relation is non-linear. The explanation is certainly to be sought somewhere else, at least in the case of shellac-moulded articles. It may be due to purely thermal effects owing to the very low thermal conductivity of these materials or to any thermal-electric effect as proposed by Rogowski in his thermal-electric theory.

The nature of breakdown.—The nature of breakdown in shellac discs has been shown in a few photomicrographs (Plate VIII). The puncture is almost invariably associated with a small crater formed by the melting of the resin on the upper side of the disc, *i.e.*, the side on which rested the sphere electrode. Sometimes this puncture is also accompanied by side-cracks. Various patterns for such cracks have been obtained, but mostly they are short crack lines emanating from the puncture-hole. Small indentations around the crater have also been noticed probably owing to collision of ions moving with high velocity in the intense electric field. The crater is indicated in the plate in (A) and (C) by the black enclosure around a white spot, which is the puncture pin-hole, and in (B) by the black spider-like picture at the centre, from which start three crack-lines. The two crack-lines in plate (A) emanating from the crater may also be seen. The puncture-hole in (B) cannot be seen, since it was inclined to the surface of the specimen, and so in the photomicrography light could not pass straightway and fall in the field of view.

It was noticed that for lac specimens puncture almost invariably occurred some distance away from the centre. In the work for the British Electrical and Allied Industries Research Association also a similar effect was noticed for high-grade dielectrics. A theoretical treatment for this effect has been given by Whitehead[10] and he has shown that this distance should increase with the thickness of the specimen as well as with the radius of the sphere, but measurement of this distance gave no definite conclusions in the case of shellac-urea-formaldehvde-wood-flour composition, since abnormal variations were found from sample to sample. Naturally other factors were present. For pure shellac specimens, however, the variation was small, but still the distance of puncture from the axis of the centre electrode, even for specimens of the same thickness, was not always the same. This only suggests the presence of some weak spots or conducting filaments through which the main current is concentrated and ultimately results in breakdown as proposed by Wagner in his Local Instability theory.

The cracks that have been observed to develop near the puncture-hole seem to be due to thermal effects. Probably they are caused by the sudden cooling of the lac disc after it has been melted by the heavy current at the point of puncture, or even they may result from sudden heating at the weak spot at the time of puncture. In one instance, however, three crack lines (Plate, D) were observed to originate from a point which was situated at a distance of about 8 mm. from the puncture-hole. A serpent-like pattern on the surface of the disc was also noticed to emanate from the puncture-hole in this case, and heading towards the point from which started the three crack-lines. The explanation probably is that there were two weak filaments of about the same conductivity on the part of the material covered by the uniform field of the electrodes. On gradually increasing the voltage stress, instability started at a certain instant of time through the two weak filaments. At the next instant, as the voltage was raised still more, the higher voltage stress was sufficient to cause a puncture through the nearer weak filament. The breakdown through this filament may either be due to its slightly higher conductivity or to the slightly more intense field, the filament being situated near the axis of the sphere electrode. Just before breakdown, however, comparatively heavy current was passing through both these weak spots and the pattern is only an automatic record of a spark or current-path through the other filament. This recording was made possible by slight melting of the resin owing to intense heat of the spark. Cracks, however, developed at the other filament due to thermal effect only. The puncture did not occur at the second spot since the stress was lessened due to breakdown having occurred through the nearer weak spot at the previous moment.

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